THE PAN-PACIFIC ENTOMOLOGIST
86(4):111–118, (2010)

Trapping Douglas-fir beetle (*Dendroctonus pseudotsugae*) with pheromone baited multiple-funnel traps does not reduce Douglas-fir (*Pseudotsuga menziesii*) mortality

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Abstract. Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) (DFB) causes considerable mortality to Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in western North American forests. We evaluated the use of semiochemical-baited multiple-funnel traps for the protection of small, high-value stands of trees, such as those occurring in campgrounds, rest areas, and small parks when Douglas-fir mortality caused by populations of DFB were at levels of concern to land managers. At two sites in western Montana in 2004, three treated plots were surrounded by three trapping stations arranged in an equilateral triangle (200 m per triangle side). Similar, untreated plots were used for comparison. More than 2 million DFB were trapped and removed from treated plots during 2004, but this trapping did not protect Douglas-fir at either site. Conversely, the ratio of infested to living trees increased substantially due to trapping at one of the sites. Placing semiochemical lures adjacent to stands of susceptible trees may have concentrated beetles from the surrounding area. Though many beetles were trapped, large numbers of beetles did not enter the traps and consequently attacked trees in our plots. Positioning pheromone traps immediately adjacent to high-value Douglas-fir stands when beetle population densities are high, does not appear to reduce overall tree mortality in target stands and sometimes increases it. However, trapping combined with sanitation and/or and antiaggregant may be a viable treatment.

Key Words. Semiochemical, insect trapping, Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), Lindgren funnel trap.

Introduction

In western North America, the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) (DFB) is the most important enemy of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), (Furniss and Carolin 1977). When DFB populations are at endemic levels, they tend to attack recently killed trees or trees weakened by ice, fire, or wind (Rudinsky 1966, Furniss et al. 1981). Under normal environmental conditions, small groups of trees can be killed, but when large numbers of trees are weakened by drought, disease or fire, DFB populations can increase and attack larger numbers of trees (Furniss et al. 1979). Outbreaks may endure for three-to-five years and attacks on groups of 100 or more adjacent trees are not uncommon (Schmitz & Gibson 1996). Although vegetation management such as thinning or removal of particularly susceptible trees may help prevent bark beetle-caused mortality (Fettig et al. 2007), forest managers need alternatives to address incipient outbreaks, particularly in or near high-value areas such as recreation or administrative sites.

Attractive semiochemical lures in Lindgren multiple-funnel traps have been used to suppress engraver beetles (*Ips* spp.) (Gibson & Weber 2004, Shea & Neustein 1995), spruce beetles (*Dendroctonus rufipennis* Kirby) (Werner 1994), and DFB (Sturdevant 2002a, b; Blackford 2007). In these studies however, the trapping projects were carried out in beetle populations that were localized in small stands (less than 40 ha) or at low-to-moderate population levels. Semiochemical signals can be used to manage DFB by aggregation and/or anti-aggregation. Bentz and Munson (2000) used multiple-funnel traps in combination with selective harvest of infested trees, and trap trees to suppress spruce beetle populations. These methods have been pursued for more than 30 years (Knopf & Pitman 1972, Thier & Weatherby 1991, Ross et al. 1996). Multiple-funnel traps baited with aggregation semiochemical components have been used to monitor DFB populations and reduce Douglas-fir tree mortality over small isolated pockets of DFB activity (Vandygriff et al. 2000; Sturdevant 2002a, b; Blackford 2007). Ross and Daterman (1997), influenced the spatial distribution of DFB caused tree mortality with pheromone-baited multiple funnel traps by concentrating DFB in areas near the baited traps. Their results indicated traps should be placed in areas where tree mortality will be least disruptive to management objectives. Ideally, traps should be placed in areas suitable for sanitation harvesting, where DFB attack trees adjacent to the traps could be removed. Trapping beetles with attractant semiochemical-baited traps can lead to "spill-over" where the beetles are attracted to the trapping area but attack adjacent trees rather than entering traps. The advantages of multiple-funnel traps include flexibility in trap placement; attractiveness throughout the DFB flight period, and virtually unlimited capacity to trap beetles (Borden 1989). The major disadvantage of traps is the need for regular maintenance by weekly removal of beetles throughout the DFB flight period.

There have been some attempts to protect Douglas-fir by using semiochemical signals to disaggregate beetles to prevent attack of trees. Examples in Oregon using aggregation chemicals have concentrated beetle-caused tree mortality in the vicinity of the traps (Ross & Daterman 1997) and reduced DFB-caused mortality up to 800 m from such traps (Sturdevant et al. 2004). In two studies, Sturdevant (2002a, b) provide evidence that traps baited with semiochemical lures may reduce DFB-caused tree mortality in stands of fire-injured Douglas-fir. In contrast to the effects of aggregation chemicals, antiaggregation pheromones have been used to disperse DFB and protect Douglas-fir stands (Ross & Daterman 1994). Blackford (2007) prevented build-up of DFB populations in high-value Douglas-fir in residential sites and adjoining National Forest land. Suppression tactics were deployed because Douglas-fir beetle populations were building in downed Douglas-fir as a result of an avalanche.

Prior to the active wildfire year of 2000, DFB populations in Montana were at endemic levels on the Helena National Forest (Sturdevant 2002b), and were increasing on the Bitterroot, Flathead and parts of the Lolo National Forests (Gibson 2002). Wildfires that burned large areas of western Montana in 2000 caused an abundance of fire-injured trees with reduced vigor and increased susceptibility to DFB attack. The fire-injured trees enabled high DFB reproduction, causing outbreak levels of DFB with more than five trees attacked per hectare. Additionally, trees were stressed by severe drought over large areas of Montana for four or more consecutive years (http://nris.state.mt.us/Drought/status/). Persistent drought conditions aided the already building DFB populations by further reducing tree vigor and the trees ability to successfully defend against attack. As a result, the DFB outbreak continued over much of western Montana through 2004.

The objective of our study was to assess the efficacy of multiple-funnel traps (Lindgren 1983) baited with DFB aggregation semiochemical components as a tool to protect small (< 10 ac, 4 ha), high-value stands of Douglas-fir, such as those occurring in campgrounds, rest areas, and small parks. We hypothesized that surrounding high-value stands of Douglas-fir with semiochemical-baited multiple funnel traps would capture and remove local DFB populations thus protecting trees within these high-value sites.

Methods

Study sites were east of the Continental Divide in the Beaverhead-Deer Lodge National Forest near Wisdom (45.7° N, 113.6° W) and Philipsburg (46.3° N, 113.3° W) Montana. Wisdom and Philipsburg are 1844 and 1609 m above sea level, respectively and are separated by about 80 km. Both sites were dominated by Douglas-fir (> 90%), but had smaller components of other species such as lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), and aspen (*Populus tremuloides*).

In March, 2004, three replicates of two treatments (trapped, untrapped) were installed at each of the two sites on 0.81-ha circular plots arranged in a randomized complete block design. DBH (diameter at breast height) of all trees > 30 cm within the 0.81 ha plots were measured. All plots were separated by at least > 1 km and contained > 5 DFB-infested trees per hectare (Phillipsburg: control 31 (10.2); treatment 27 (2.9); Wisdom: control 17 (2.9); treatment 6 (1.4)) at the beginning of the study. Plots with traps had three trapping stations arranged as an equilateral triangle (Fig. 1). Each trapping station had three semiochemical-baited 16-funnel traps hung from a pole with the bottom funnel 1 m above the ground. Traps were spaced 10 m apart in a triangle. A 2.5 cm piece of No-Pest Strip® was placed in each trap cup. Traps were located in stands of non-host trees, areas of prior Douglas-fir tree mortality, or among small-diameter Douglas-fir that were unsuitable as DFB host trees. This was done to avoid or reduce the likelihood of "spill-over" where beetles are attracted to the lures but attack nearby host trees rather than being caught in the traps. Semiochemical baits (frontalin 300 mg releasing 2.5–3.0 mg per day from a pouch, seudenol 250 mg bubble cap releasing 1–2 mg per day, and ethanol 12 g LR releasing 15–20 mg per day from a pouch; from Synergy Semiochemical, Burnaby, BC, Canada) were placed in the traps prior to DFB flight in March and replaced after eight weeks to insure the presence of active lures for the duration of beetle flight.

Traps were emptied weekly, and beetles were packaged, frozen, and transported to the lab where they were counted. The number of live trees > 30 cm dbh in each trapped and untrapped plot was recorded prior to new beetle attacks in spring 2004 and 2005. The number of trees attacked by DFB during summer 2004 and 2005 was recorded in the fall 2004 and 2005. Trees that had red or yellowish-red boring dust around the circumference of the tree were scored as attacked.

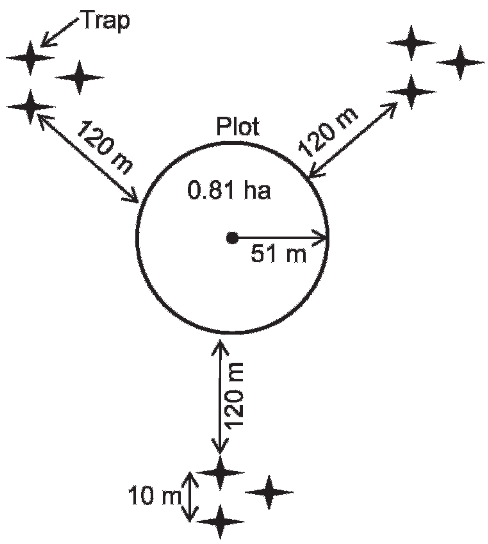

Figure 1. Arrangement of Douglas-fir beetle pheromone traps around plots in a study that evaluated effects of beetle trapping on Douglas-fir mortality in western Montana.

Data Analysis

We fit the following model:

$$y_i \sim N\left(\mu_{j(i)} + \alpha_{k(i)} + \beta_{l(i)} + \gamma_{m(i)} + \delta x_i, \sigma\right) \tag{1}$$

where y_i is the ratio of attacked to living trees, with living trees counted prior to new beetle attacks in Spring 2004 and 2005, and N(mu, sigma) is the normal distribution with mean mu, standard deviation sigma. Transformations are often applied to ratio data, but we did not apply a transformation because the residuals were approximately normally distributed with constant variance. The observation index i ranged from 1 to $24 = 12$ plots $\times$ 2 study years. The μ are site means with $j(i)$ signifying site membership. For example, $j(8) = 2$ signifies the 8$^{\text{th}}$ observation is on Site 2 which was the Philipsburg site. The α are plot effects, the β are year effects, and the γ are site-specific pheromone trapping effects. The number of live trees in plots prior to each year's beetle attack is given by x_i, and this predictor was included because the data suggested a positive relationship between y_i and live tree density. The x vector was standardized to mean 0, standard deviation 1.

Our Bayesian approach required assigning prior distributions to all parameters. The α were assumed to follow a normal distribution with a mean of 0, and a standard deviation τ. All other parameters were assigned uniform distributions, except the random error variance which was assigned: $p\left(\sigma^2\right) \propto 1/\sigma^2$. These are standard, non-informative priors (Gelman et al. 2004). We used a Gibbs sampler constructed in FORTRAN to simulate the joint posterior distribution of model parameters (Intel Corporation 2003) and used 95% Bayesian confidence intervals to summarize the marginal distributions of the pheromone trapping effects.

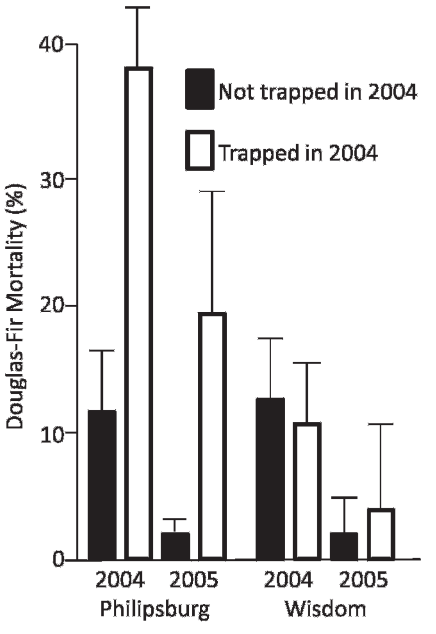

Figure 2. Percent of trees killed by Douglas-fir beetles in a western Montana study that evaluated effects of surrounding forest plots with pheromone traps. Lines denote standard errors.

Results and Discussion

We collected an average total of 23,794 and 35,338 DFB per trap at Wisdom and Philipsburg, respectively. The traps did not protect Douglas-fir greater than 30 cm DBH (Fig. 2), substantially. Conversely, confidence intervals on the difference between trapped and untrapped means show that tree mortality increased substantially due to trapping at Philipsburg but not Wisdom (Fig. 3). It appears that the traps lured large numbers of beetles to the Phillipsburg plots, and whereas some beetles entered the traps, others increased Douglas-fir mortality by attacking trees nearby. The lower limit of the Philipsburg confidence interval suggests beetle trapping increased tree mortality by at least 12%.

Although trapping was conducted solely in 2004, effects from the trapping year carried over to the following year. By fitting a preliminary model that included year-specific trapping effects, we concluded that initial and carryover trapping effects were of similar magnitude. Consequently, we used the same confidence intervals to describe trapping effects for both 2004 and 2005 (Fig. 3). It appears installing traps baited with semiochemical lures in 2004 increased beetle densities and subsequent related tree mortality at Philipsburg, and beetle densities and tree mortality remained elevated through 2005.

In plots near Philipsburg, mean Douglas-fir density was 513 trees per hectare with a mean DBH of 29.2 cm (Table 1). Near Wisdom, Douglas-fir tree density was lower (236 trees ha^{-1}), but DBH was greater (35.6 cm). The 95% confidence interval describing the relationship between tree density and tree mortality is (0.001, 0.010). This positive confidence interval suggests plots containing above average live tree density (i.e., average = 234 trees per plot) experienced above average tree mortality. The most likely value for the tree density parameter is 0.05, and this value suggests

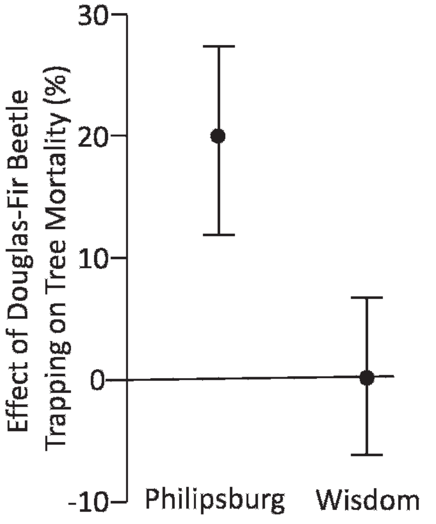

Figure 3. Most likely parameter estimates (dots) and 95% confidence intervals (lines) describing changes in Douglas-fir mortality caused by surrounding plots with pheromone traps in a study in western Montana. Zero denotes no effect of trapping, and positive values indicate increases in percent mortality due to trapping.

each 1 standard deviation (i.e., 1 SD = 135 trees per plot) increase in tree density corresponds with a 5% increase in tree mortality. The positive relationship between density and mortality supports previous findings of a preference by beetles for more densely forested areas (Weatherby and Their 1993, Negron 1998, Negron 1999). Negron et al. (1999) showed increasing basal area killed by DFB with increasing overall basal area.

At endemic levels Douglas-fir beetle generally resides in wind-thrown, injured, or root diseased trees. Tree mortality associated with endemic populations of DFB is widely scattered throughout forested landscapes, killing small groups of trees. When DFB are at low to moderate densities (average of several infested trees per ha.), baited funnel traps alone have been shown to reduce tree mortality (Sturdevant 2002a, b; Sturdevant et al. 2004). Pheromone-baited multiple-funnel traps can also be combined with other control methods to reduce beetle caused mortality. Blackford (2007) used pheromone-baited multiple-funnel traps to attract beetles and MCH (3-methyl-2-cyclohexen-1-one) to discourage aggregation in surrounding areas in a "push-pull" strategy employing a semiochemical anti-aggregant (MCH) to

Table 1. Mean (SE) percent species composition by basal area, mean (SE) DBH, and mean (SE) basal area for all trees at study plots at Philipsburg and Wisdom, Montana.

Location	Species	Mean composition (%)	Mean DBH (cm)	Basal area
Philipsburg	Douglas-fir	90 (0.011)	37.59 (0.73)	324.04 (38.49)
	lodgepole pine	6.3 (0.017)	26.67 (1.21)	22.66 (13.82
	Engelmann spruce	2.7 (0.007)	26.035 (1.40)	14.92 (6.39)
	subalpine fir	1.0 (0.005)	20.42 (1.32)	5.44 (2.15)
	Douglas-fir	94 (0.25)	49.75 (1.45)	267.78 (17.21)
Wisdom	lodgepole pine	5.75 (0.01)	24.56 (1.52)	19.80 (4.43)

"push" beetles away and an aggregation lure to "pull" beetles toward traps. This effort was undertaken where an avalanche had damaged Douglas-fir, rendering the trees susceptible to beetle attack (Blackford 2007). Similar methods have been used by Ross and Daterman (1994). Removal of nearby infested trees (sanitation logging) has also been used to improve trap tree treatment efficacy to reduce DFB-caused tree mortality (Fettig et al. 2007).

Positioning attractant semiochemical baited traps alone, adjacent to high-value Douglas-fir stands does not appear to deter beetle infestation and sometimes increases it. At outbreak population levels of more than 10 infested trees per ha, pheromone trapping of DFB by itself is not an effective means for protecting small, high-value stands of trees. Our study was conducted when DFB were at levels that caused concern among land managers who requested intervention.

Although we placed our baited traps in areas of non-host, dead, or Douglas-fir trees to small to be suitable hosts for DFB, the residual DFB population that were not trapped or were lured toward the traps by not captured resulted in more trees killed in the trapped plots than the untrapped plots in the Phillipsburg area. Possibly, our traps were placed too near the high value stands. Positioning pheromone traps adjacent to high-value Douglas-fir stands does not appear to prevent beetle infestation and sometimes increases it.

Acknowledgments

This project was funded by the USDA Forest Service, Forest Health Protection, Western Bark Beetle Initiative, 2005. The authors extend their appreciation to Ken Gibson for assistance in the field and manuscript reviews and to Chris Fettig, Bruce Hostetler, Rick Kelsey, Jose Negron and Don Scott for helpful reviews.

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Received 27 May 2010; Accepted 24 Nov 2010; Publication date 10 June 2011.